Roe Herring Impoundment Research - Report on the 1981/1982 Studies

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ABSTRACT

Kreiberg, H., J. R. Brett, and A. Solmie. 1982. Roe herring impoundment research - Report on the 1981/1982 studies. Can. Tech. Rep. Fish. Aquat. Sci. 1149: v + 45 p.

A second year of testing the impounding of herring in floating netpens in Departure Bay, British Columbia, was conducted. The object is to diversify the roe herring fishery and preserve traditional spawning grounds from any detrimental effects of commercial fishing.

Based on the success and insight of the first pilot-year using small experimental netpens, two large netpens (27 m × 9 m × 7 m)were designed and subsequently loaded in January 1982 with 22 tons of herring each, at an established safe level of 8 kg/m^3. The smaller netpens (and tanks) were also loaded to recheck density impact, temperature and salinity effects on maturation and spawning, and to monitor gonad development at the fishfarm location without regular sampling disturbance of the 'commercial' netpens.

Test sale of the mature herring was conducted by auction in late March. The product was followed through processing, and an economic assessment made. High survival (93%), excellent condition of the roe, and generally low costs resulted in a favorable economic outlook for roe-herring impoundments.

A third and final test year involving a new field site and seine-towed herring (as well as barged fish) will complete the commercial test phase of the impoundment study.

Key words: herring, impounding, survival, maturation, roe quality, body composition, commercial sale, roe processing, economic assessment.

RÉSUMÉ

Kreiberg, H., J. R. Brett, and A. Solmie. 1982. Roe herring impoundment research - Report on the 1981/1982 studies. Can. Tech. Rep. Fish. Aquat. Sci. 1149:: v + 45 p.

Le présent rapport porte sur une seconde année de captivité expérimentale de harengs dans des enclos flottants en filet, dans la baie Departure (Colombie-Britannique). Il s'agit de diversifier la pêche du hareng rogué et de protéger les pêcheries traditionnelles contre toute l'incidence nuisible résultant de la pêche commerciale.

Par suite du succès obtenu et de l'expérience acquise au cours de la première année pilote avec de petits enclos en filet expérimentaux, deux grands parcs en filet (27 m × 9 m × 7 m) ont été conçus pui, en janvier 1982, chacun a été rempli de 22 tonnes de hareng à un taux sûr de 8 km/m^3. Les petits parcs en filet (et les bassins) ont aussi été chargés pour permettre de vérifier à nouveau l'effet de la densité, de la température et de la salinité sur la maturation et la fraie et de surveiller le développement des gonades à la piscifacture sans déranger l'expérience dans les parcs en filet "commerciaux" par des échantillonnages réguliers.

Une vente expérimentale de harengs matures à l'encan a eu lieu à la fin de mars. On a suivi le produit pendant toutes les phases du traitement, après quoi une évaluation économique a été réalisée. Le taux de survie élevé (93%), l'excellente condition de la rogue et les coûts généralement faibles se traduisent par une perspective économique favorable pour la mise en captivité de harengs pleins.

La phase de vérification commerciale de cette étude sur la mise en captivité comprendra une troisième et dernière année d'expérimentation dans un nouveau site avec du hareng remorqué à l'aide d'une senne (et transporté par barge).

Mots-clés: hareng, mise en captivité, survie, maturation, qualité de la rogue, composition du corps, vente commerciale, traitement de la rogue, évaluation économique.

I. INTRODUCTION

This report covers the second year of a 3-year study of impounding adult herring for testing control of quality and timing of roe production. Year 1 of the study is described in Brett and Solmie (1982). The study was established in 1980 with the initial aim of identifying "the most critical biological and technological problems of capturing, transporting, and impounding maturing herring" by conducting a small pilot operation. Following the successful 6.5-ton impoundment in 1980-81, the expanded study for 1981-82 was divided into 2 sections, one dealing with a 40-ton commercial test-operation and the other with continued experimental and monitoring requirements.[1]

As in Year 1, the present work was formulated in part to prepare the operators for the next year's activities. Experience reported here, notably in the handling of the 2 large 20-ton netpens and the conduct of the commercial sale, will be applied in the final year of the study. This will involve a field operation designed to resemble in every respect a commercial roe-herring impoundment, complete through to harvest by a processor.

Priority areas of research, first established for the 1980-81 season, were redefined. For 1981-82, in declining order these were a) density-stress-disease relationship, b) effect of time of capture, c) delay of spawning, and d) effect of temperature, salinity, and spawning releasers. Experiments at the Departure Bay fishfarm, as well as the laboratory, addressed these questions. Once again, the scope of the problems required the co-operative efforts of experts in disease and in roe quality and body composition. Further, a Departmental economic evaluation was included. These related studies are referred to in the text, and are included as a section.

For continuity, the reporting follows the form established in the 1980-81 report. Hence, a brief overview of the findings is first presented, followed by more detailed accounts of the new aspects of the second year.

II. SUMMARY STATEMENTS

1. CATCHING AND TRANSPORTING OF HERRING

A total of 47.9 tons of maturing herring were caught by seine during 7 days in early January, in Stuart Channel, Gulf Islands region. Two barges

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[1]Throughout this report, the two 20-ton commercial-test pens will be referred to as L1 and L2. All other netpens are described by H-numbers as in the first report. Also, ton is used instead of tonne, because of the long experience of estimating catches in this unit.

(4-ton and 7-ton capacities) each with a tow vessel were used to transport a total of 10 loads of herring approximately 32 km to the Departure Bay site. With the exception of the problem of sea lions (in all but one set), seining proceeded smoothly. No sure method was found to discourage sea lions from interfering with fishing operations, and their increasing presence in local populations, and their aggressive feeding behavior, may pose a serious problem for impoundments.

2. SITE AND HOLDING FACILITY

Newly-designed netpens with dimensions of 27 m × 9 m × 7 m, and equipped with an opening gate for transferring of barged herring, were used. They proved to be both seaworthy and manageable, easy to handle, and capable of holding safe densities in excess of 8 kg/m^3 while permitting herring to sound and school naturally. The Departure Bay site again proved itself a near ideal location, being well-protected and experiencing relatively stable temperature and salinity.

3. BASIC RESULTS

Herring survived exceptionally well in all netpens for the 4-month period 5 January-5 May 1982; losses for that duration averaged only 6.8%. An effort to check 1980-81 experience with high density (16 kg/m^3 density had resulted in 33% mortality by spawning time) produced no excessive mortality by spawning time. The large commercial-test pens recorded excellent survival to harvest 75 days after impounding, 2.9% mortality in pen L1, 10.0% in pen L2 (latter was expected to be higher due to adverse catching history). Simple methods developed to predict time of maturation 1.5 months in advance were proven accurate to within a day or two. Maturation progressed from a gonosomatic index (GSI=gonad weight as percent of body weight) in females of approximately 11 in early January to an average of 25 by late March. Spawning occurred in most pens over the period late April-early May, 115 to 130 days after capture. Quality of roe increased to a peak by late March with 71-89% at a rating of "No. 1 and No. 2 Mature[2]", and remained high for 3 weeks or more. Late capture, in mid-February, resulted in no difference in maturation rate or timing. All stocks matured synchronously, male and female, and remained at GSI (♀) = 25 for an average of 40 days. The commercial-test operation was fully successful, commanding a comparatively high price for the 42.3 tons of roe herring sold ($1151/ton) and drawing favorable comment from the processor. The harvest was spread over 2 weeks with no incidence of spawned-out fish or change in product quality. Roe yield by the standard Fisheries Officer test averaged 13.7 ± 1.9 SD.

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[2]See section XII, Co-operative Studies, Quality of roe.

4. MODIFYING FACTORS

Tank experiments were conducted to determine effects on spawning of temperature, salinity, and spawning releasers. A clear temperature effect was noted, spawning occurring earlier and more fully at higher temperatures. As well, losses were higher over a 60-day period at higher temperatures. Salinity did not appear to have any pronounced effect on time of spawning.

III. CATCHING AND TRANSPORTING HERRING

1. CHARTERS

Catching of herring was done by the seiner MARY ROBERTA under Richard Johnson; a second vessel, HERRING GIRL, with live-barge BILL'S ARK was under William Cameron (described in Brett and Solmie 1982). Additional support was drawn from the 19-m Fisheries and Oceans research seiner CALIGUS, towing Johnson's live-barge LIVEWAY. The latter craft was modified from a surplus mold used to produce a standard design gill-netter hull. With a V-type hull and 2 internal bulkheads, it measured 5.5 m × 19.8 m, drawing 1 m unballasted, and was equipped with bow and stern ballast tanks. A shallow 2-m × 1-m lip at the stern served as a loading gate; unloading was by 1-m × 0.5-m screened opening ports in the side. Small ports, 1 m × 0.5 m, allowed movement of water and herring between compartments. The LIVEWAY could not be pumped as nearly dry as BILL'S ARK and was not as readily unloaded.

2. CATCHING AND TRANSPORTING OF STOCKS

Most of the fishing was conducted in the period 6-13 January 1982 for a total of 13 sets; the 14th and final set was made on 15 February 1982. All productive sets were made in the Ruxton Pass area off DeCourcy Island, in Stuart Channel. The transfer procedure, from seine to barge, was as described in Brett and Solmie (1982). The need for seamanship and skill in carrying out this process was emphasized by one set during which delays allowed the full seine to drift and deform. As a result, the fish suffered some scale loss and bruising, reflected in a higher mortality (10.0% vs 2.9%) in commercial-test pen L1, where this stock was placed. All other loads of fish were judged to have arrived at Departure Bay in good condition.

Except for the first 4 sets, which were non-productive, all sets bar one were troubled with sea lions both around and in the set (range of 2-8 in each set). The animals appeared to be attracted by the necessary activity and light surrounding night fishing operations, and were not repelled noticeably by underwater 'seal bombs' or rifle shots. During the process of 'drying-up the net', their escape over the corkline could be facilitated, however it was

impossible to eliminate 'boil-ups' and other signs of fish stress due to sea lions. We did not manage to add knotless bunt to the seine used - a recommended step yet to be applied. By-catch other than sea lions was minimal, consisting of groundfish, [principally midshipmen (Porichthys notatus)], and small squid (Loligo sp.). By-catch was generally excluded from the barges without special effort. Dogfish (Squalus sp.) were not a problem. A total of 5 herring tags was recovered from the catches, all having been placed in November 1981 in the Stuart Channel area.

Barges loaded with herring were towed at speeds of up to 5 knots without causing undue stress to herring. A tow speed of 2 to 3 knots was more usual, allowing adequate water exchange, economical engine speeds, and safety (ballasted displacement of the LIVEWAY, for example, was 75 tons). Continuous recording of dissolved oxygen levels in loaded barges under tow (YSI model 56 recording oxygen meter) revealed small fluctuations ($\pm$ 1 ppm O_2) about means of 8 ppm O_2 (in excess of 75% saturation). In general, oxygen levels in loaded barges remained more than adequate, provided the barge was kept moving. A barge recording made including a 3-hour period of drifting while waiting for slack-tide through Dodd Narrows showed a distinct downward trend in oxygen, to a minimum of 60% saturation, before the tow got under way again. While in tow, the herring distributed themselves evenly throughout the compartments of the barge on most occasions, swimming slowly in all directions in a horizontal plane. They were unable to school, but no other fright responses were noted. When a lantern beam was shone on them, they merely moved slowly out of the beam. Of significance in barge design is the fact that herring are reluctant to swim up over a sill in order to leave a confined space. It is apparent also that for a given mass of fish, there is a distinct minimum requirement for size of an opening through which they are to pass. Ports in bulkheads, as well as unloading ports, should be designed with generous proportions of $1 m^2$ or more.

IV. SITE AND HOLDING FACILITY

The basic description of the site and its predator protection remained as in Brett and Solmie (1982) including the use of a guard-dog. As in 1980-81, there was no need to isolate the entire farm with the available wrap-around predator net. Differences between the first year's and the present work are described as follows, having to do with the commercial-test pens or modifications of procedures used in 1980-81.

1. STOCKING, NET HANDLING, AND SAMPLING

A 30.8-m × 21.5-m longitudinally-divided float capable of housing two 27.7 m × 9.2 m × 7.6 m-deep netpens was designed and constructed for impounding about 40 tons of roe herring. The float was assembled from sections of Topper Industries T-23-F design floats. Additional flotation was

incorporated to accommodate increased weight from mooring chains and a centrally-located laminated beam spanning the full width of the float.

Each float was designed with a 6.1-m × 1.5-m opening gate section at one end to allow for the transfer of herring either from a seine or from a live barge. This section of float was held in place by a pin and bracket system for easy removal while still maintaining strength enough to hold the float configuration during unfavorable weather conditions encountered at the mooring site, e.g. swells, force 5-6 winds.

The new, large commercial-test pens were constructed using a 210-30 white knotless nylon 22-mm stretched mesh, hung to maintain a box-like shape. The configuration was maintained by a variety of laced supporting lines of braided nylon, namely: a 16-mm borderline, four 13-mm corner lines, two 10-mm transverse rib lines (9.2 meters apart and led across the bottom of the pen), a horizontal 10-mm rib line placed halfway down the side of the netpen, and finally a 50 kg per 100 fm lead-core leadline around the bottom perimeter of the netpen.

For securing the netpen to the float, thimbles were attached at all corners and at the top and bottom of each vertical rib line. The top thimbles were secured to ring bolts on the decking of the float. The bottom thimbles were attached to down-haul lines passing through the eyes of the 100-kg anchors independently suspended from the float. (For detail see pages 17 and 83 of the Fisheries and Marine Services Industry Report No. 107, by Kennedy 1978.) The float itself was moored against a dolphin, and anchored at each exposed corner with pairs of 363-kg rail-car wheels pulling at right angles to each other. A log boom protected it from debris and heavy wave action.

Removal of the netpens for cleaning and storage was easily carried out. The gate section of the float was opened and a vessel equipped with a seine drum backed into the net pen area. Nylon ropes were attached to the netpen top corners for winding onto the drum after all securing lines from the netpen to the float had been released. In this way each large netpen was delivered to the main float for cleaning with an 800 PSI pressure seawater pump.

Observations conducted during netpen handling and cleaning resulted in the following findings:

(a) most fouling occurred in the top 3 meters and consisted of a brown slime which was mostly a combination of threadlike chains of diatoms, other algae and accumulated silt. No mussel spat had settled in the three month period (Jan.-Mar.).

(b) the lower portions of the netpens were relatively free of fouling and remained fairly white.

(c) all fouling was easily removed by the pressure pump during cleaning.

2. PREDATOR PROTECTION

To control known predators (dogfish, seals, birds, mink, and otters) the following precautions were taken:

(a) the large commercial-test netpens were enclosed in an outer net made from 88-mm salmon seine web. This predator net was secured to the top inside perimeter of the main float. The down-haul lines from the herring pen passed through the predator web at the bottom corners and at the bottom sides of the predator net opposite the anchors used for maintaining the box shape of the herring pen. These anchors then held both nets in a box-like shape while still allowing the herring netpen to be lifted independently of the predator net.

Netpen covers were also made from 88-mm salmon seine web. These were kept from dipping onto the surface of the water by stringing 12-mm nylon ropes across the net pen at 9-m intervals and also by attaching the cover to the center cross-beam of the float.

(b) The smaller experimental and monitoring netpens had no predator protection other than netpen covers except in two situations. In the first case, the 2 monitoring pens associated with the commercial-test pens had gillnet mesh suspended around them, as mink persisted in chewing holes in the pen sides. The other situation was brought about late in the project by a large number of dead fish resulting from an unsuccessful live-pumping experiment. Attracted dogfish chewed through the bottom of the pen, but a predator net suspended below the netpen [method described in Brett and Solmie (1982)] solved the problem.

Predators found trapped in the web of the protecting nets consisted mainly of dogfish, a few diving ducks, occasional lingcod, rockfish and ratfish, and 2 otters. The predator nets were not intended to trap sea-animals, merely to discourage their attention. Although sea lions were observed once near the netpens there was no physical damage done, nor did they appear to cause undue stress to the stocks.

V. HANDLING AND DISTRIBUTION OF FISH

1. FISH TRANSFERS

Two different barges were used to transport the herring from the catching site to the holding pens. The first barge, designed for both stern loading and unloading, backed through the open gate section of the float up to

the netpen. The top edge of the netpen was released at the corners from the main float allowing enough slack in the borderline to be wrapped around the barge door collar, forming a seal. The door was then opened and the fish allowed to swim into the netpen as the forward ballast tanks were pumped dry. This barge was flat-bottomed and slab-sided, specifically designed for transporting live fish; therefore, unloading was very quick and caused little stress to the herring.

The second barge was stern loading, over a shallow lip, and utilized one of the side ports for unloading. Hence, the barge could only come alongside the opened gate section of the float. A small mesh apron was therefore fixed to the unloading port and draped over the center of the top and borderline of the pen. The netpen was released from the float at the near corners; a short piece of chain was then draped over the borderline causing the netpen and apron link to settle into a U-shaped "trough" through which the fish could swim into the netpen. Because this barge was only temporarily modified for transporting live fish, the herring had to be crowded from each hold of the barge to the unloading port with a small seine. This was both time-consuming and stressful to the herring. There was always a residue of herring (up to 1 ton) left in the barge that could not be readily driven out.

2. PROCEDURES FOR REMOVING SAMPLES OR MORTALITIES, AND HARVESTING

To provide for regular sampling and removal of mortalities, the large netpens were designed with lifting rings every 3 m along the leadline on the long (27.7-m) sides of the pen. The following procedure for lifting could be carried out by two people, one on each side of the pen. First, all down-haul lines were released so that the netpen was free to move. Next, lifting lines in the center area of the pen were hauled on, raising the bottom of the netpen to the surface, thereby dividing it into two halves. This action could be timed to coincide with fish movement up and down the pen so as to isolate a suitable number of fish in one half. The lifting lines were then raised one at a time, working towards the end of the pen and crowding the fish. As each consecutive lifting line was raised, the previous one was released. Once suitably crowded a representative sample could be taken.

To remove mortalities the same process just described was used with the exception that the bottom of the netpen was not raised to the water surface. The original lifting line was kept in a three-quarters-up position while the next one was released when the third lifting line was lifted. This allowed the live fish to escape to the opposite end of the pen while the mortalities rolled along the bottom to the end of the netpen. The last section was then fully lifted to remove the mortalities.

For harvesting a portion of the stock in a large netpen, a smaller "transfer" netpen complete with its own float was brought alongside the open gate section of the 27.7-m netpen. The top borderline of the net from the small pen was laced to the top end borderline of the large netpen, the corners having been released. A short piece of chain draped over the midpoint of the joined borderlines was used to sink the borderlines approximately 2 m below the surface. The lifting lines were then used in the manner described for

sampling live fish to crowd the fish into the smaller net. To remove the last few tons of fish, the lifting was begun at the extreme far end of the large netpen. It was found unnecessary to herd the fish by any other means than the lifting lines; it was prudent to shut off nearby engines and avoid sudden noise or movement during the transfer process. Once loaded, the transfer net could be quickly unlaced, secured to its own float and pushed to dockside by 2 small work-boats.

The transfer, lacing to unlacing, could be done in under 30 minutes. All transfers from the time the fish were caught until the time they were harvested were carried out by "swimming" the fish from place to place, ensuring low mortalities and a high quality product.

3. FEEDING

No intentional feeding was carried out in the present research. However, especially during one plankton bloom in mid-April, all pens were observed to be feeding voraciously; a sample indicated the bloom to be almost entirely the copepod Calanus plumchrus. Weekly sampling from January to May for gonad quality usually revealed little or no food substance in herring stomachs. After spawning had occurred, some pens destined for use in other research were easily weaned onto 3.2-mm (1/8") standard Oregon Moist Pellet salmon diet, using frozen euphausiid as an intermediate feeding step.

VI. ENVIRONMENTAL CONDITIONS AND MEASUREMENTS

1. TEMPERATURE (Table 1, Fig. 1)

Water temperature was monitored continuously at 3 m below surface for the duration of the impoundment period. In January and February, the weekly mean temperatures varied between 6° and 8°C, rising slightly in March, until a rapid increase in early April brought them up to 10°C. While this warming trend was a degree or more below the previous year's record, parity was eventually reached by mid-May, at 11°C, with almost all stock spawned fully. A comparison of degree-days between spring 1981 and spring 1982 showed a difference of only 5% in the totals to mid-April.

2. SALINITY (Table 1, Fig. 1)

Surface water salinity was stable at 26.9‰ ± 0.8 SD for the impoundment period.

3. TURBIDITY (Table 1, Fig. 1)

Water turbidity, measured with a Secchi disc, fluctuated from approximately 5 m to over 12 m during the 4 months of impoundment, with no clear overall trend. Changes in turbidity were not accompanied by salinity changes, hence adequate mixing of up-welled sediment and land run-off through the water column must have occurred rapidly. The overall mean was 8.4 m $\pm$ 2.1 SD, being slightly clearer compared with 7.9 m $\pm$ 1.3 SD for the previous year.

OXYGEN

A variety of situations were explored with a recording oxygen meter and 15-m cable, to assess possible hazard to the impounded herring. Situations included low-amplitude tidal cycles; slack water at low tides; crowdings for sampling fish, transferring them, or lifting netpens under them; and 24-hour diurnal plots. In none of the above situations were the combinations of fish density and rate of flushing sufficient to depress oxygen levels below what would be considered the normal range of fluctuation (70-105% saturation). Given that the nets were for the most part very little fouled, the herring appear to have had adequate oxygen levels at all times. Even during crowding situations such as when lifting a netpen to remove mortalities, tide and currents induced by fish activity more than offset the locally high oxygen demand.

4. SITE SUITABILITY

The Departure Bay site, in addition to advantages described in Brett and Solmie (1982), adapted well to expansion to commercial scale. Access with live barges was provided to both large netpens, and the proximity to the Biological Station wharf facilitated the commercial sale of roe herring. The fact should not be overlooked that a successful 4-month impoundment program was again carried out in a port area subject to frequent vessel traffic and other characteristics of populated areas. Roughly every 10 years a wild herring spawning occurs in Departure Bay; none was observed this season.

VII. STOCK CHARACTERISTICS, FISH DISTRIBUTION

1. VITAL STATISTICS

A summary of the vital statistics of the stocks is contained in Tables 2 and 3, together with measurements made on survival and maturation. With the increased scale of operations and larger number of barge loads, there was considerable mixing of stock from various sets as house-keeping arrangements were finalized. We attempted to segregate the large commercial-test pens, assigning fish from the LIVEWAY to pen L1, fish from BILL'S ARK to pen L2. Due to the LIVEWAY's greater capacity, it became necessary to add one large load off her into pen L2. All of the experimental stock (including tank experiments) was drawn from 2 sets on separate nights, both loads delivered by BILL'S ARK. Associated with each large commercial-test pen was a smaller 4.3 m-square pen for weekly monitoring purposes, to avoid continued sampling activity in the large pen. Each monitor was filled from its 'mother' pen after all catching was complete.

Initial samples of 100 herring were taken on 18 January from each of the 2 barge loads assigned for experiments. The overall sex ratio from all weekly samples favored females slightly, averaging 54%. Eight dockside determinations on the commercial-sale stock averaged 53% females. For the late capture stock, the ratio was 46% females. This was obviously a different group of fish from the source used in January's catches, as they were also a smaller fish. The incidence of immatures in early and late catch stocks was extremely low, although we feel it was not so low as indicated by sample data (early stock, n=2000, ♀=0.03%, ♂=0.02%; late catch, n=250, ♀=0%, ♂=0%, where immature = ♀GSI<10, ♂GSI<5). Processing-plant records indicate that the last 10-ton lot processed contained 6.6% immatures. The low incidence of immature fish in the commercial-sale lots did draw favorable comment from the buyer, although there are other reasons as well for this circumstance.

From scale readings of samples drawn from the experimental stock, the age classes were (year, %)4:

2(0.5%), 3(17.9%), 4(22.5%), 5(16.1%), 6(6.1%), 7(2.8%), 8(1.4%), 9(0.7%).

For the late capture stock, the classes were (year, %): 1(0%) 2(1.0%), 3(27.0%), 4(29.0%), 5(16.0%), 6(0.5%), 7(0%), 8(0.5%), 9(0%).

4A fish of age 2 would be completing the second year of its life, actually age 1+. Scale samples were taken in January and February, 4-10 weeks before the fish entered a new year of growth.

VIII. EXPERIMENTAL STUDIES

1. PLAN

The emphasis of the 1981-82 research plan developed from insight and results of the 1980-81 season. Accordingly, pen H1 was stocked to 16 kg/m^3, intentionally high, and other pens to lesser densities, in an effort to supplement a density-mortality curve prepared in the first season. Effect of time of capture was explored with a later catching and impounding. With respect to the key question of control of spawning, tank experiments were scheduled, to test the effect on maturation and time of spawning of different combinations of salinity and temperature. As well, pen and tank experiments were prepared to test the effects of possible releasers for spawning. Finally, we undertook to develop a method for predicting accurately the time of maturation, GSI(♀)=25, for our impoundment stock. While the commercial-test pens were not strictly a part of experimental studies, salient points are nevertheless included in this section.

2. SURVIVAL

As in the previous year, a post-catching period of 10 days was kept free of avoidable stress to the stocks, such as sampling, net-liftings, etc. A very small number of obviously damaged fish died during this period, with no pen experiencing over 2.5% mortality (most were less than 1%, including the 2 commercial-test pens). The fish appeared to be in good health; stomach samples taken from actual sets revealed very little contents, most stomachs being white and contracted. In the smaller pens, dimensions did not allow as natural a schooling behaviour as did the large commercial-test pens. The latter were ideal for permitting the fish to school in large groups of up to 75% of the approximately 20 tons in each pen, as well as permitting them to sound in response to surface disturbances. Although swimming occurred over a wide range of activity levels, by day and by night, no herring were seen not to swim. Their pattern of movement in the commercial-test pens was similar to that noted in smaller pens, one of steady, uniformly spaced group motions, avoiding corners and remaining 20-25 cm away from netpen walls. The latter distance diminished as time went by, to less than 10 cm by the end of March.

Regular sampling for disease monitoring turned up some signs of pathogen activity, however, no disease outbreak of any magnitude developed in even the most heavily stocked pens (see Section IX, Cooperative Studies, Disease). Beginning in February after 30-35 days of impoundment, signs of stress began to appear in weekly samples taken for gonad weights, principally light hemorrhaging on the operculum. However, mortality figures remained low through to spawning, 120 days post-catching, hence this did not indicate a serious problem.

3. MATURATION AND ROE YIELD

Progress of maturation

The gonosomatic index (GSI=gonad weight as percent of total body weight) was tracked by weekly sampling of 50 fish per netpen. From estimated levels at capture (5-10 January) of 11% (♀) and 14% (♂), the GSI rose steadily over the next 60-65 days to a plateau, 25% (♀) and 20% (♂). These results differ very little from 1980-81, where initial estimates were 10% (♀) and 13% (♂), rising to 26% (♀) and 19% (♂). In both years, males initially exceeded females in development of GSI. Curves for GSI development cross at a point between 28 January and 5 February, following which date the females' GSI exceeded the males'. As would be expected, development of GSI levels off at the same approximate date for both sexes. Fish are considered mature at the levelling-off point, although the point of greatest market value (translucent eggs) has not yet been reached. Figures 2 and 3 show the typical form for GSI development. In these and other figures, the bars for SD are shown dotted when the mean-distribution begins to become bimodal due to the presence of some spawned-out fish.

Much as in 1980-81, the first spawning took place early in April (91 days after catching), and was not followed by the majority of pens until 2 weeks later. The spawning was again prolonged and spotty, spread over a 3-week period extending into the first week of May. We observed no induction of spawning from one netpen to another, despite concerns about the possibility, and despite several examples of substantial spawnings in a netpen separated from another by less than 1 m. No marked increase in mortality accompanied the immediate post-spawning period.

Prediction of GSI development

Using data from the 1980-81 season, and results from a month of sampling in the 1982 season, we were able by 25 February to predict accurately that our stocks would reach maturity (GSI♀=25) between 12 and 15 March. The rate of GSI development is approximately linear during the 2 months preceding maturity in our impoundment stock, and yields the regression equation $y=7.842 + 0.2333x$, $R=0.96$. By this regression, GSI of 25 occurs on day 74 (15 March). Confirmation by 2 additional means provided a measure of confidence, useful to have in an animal as variable as the Pacific herring. These additional means were:

1) Graphic - transparent overlays of GSI plots from each year, to build up a visual composite of GSI development; and

2) Water temperature degree-day comparisons - while rate of maturation is probably more strongly stock-dependent than temperature-dependent, it is useful to compare spring warming trends insofar as our experience indicates that 10°C is a threshold temperature for herring spawning. It is apparent from our tank experiments, reported later herein, that temperature has a marked effect on spawning date. Where the chief aim of a roe herring impoundment is to use the delayed-spawning phenomenon to advantage, degree-day plots are useful in estimating the yield period.

We stress that the regression given above is at present specific only to the herring stock used to develop it. It is clear that with various stocks on the British Columbia coast spawning from January to May, one regression slope is not universal. A report by Whiting (1981) cites a slope of 0.27, while Ware (1982) gives a slope of 0.8 for the short 12-14 day period prior to spawning in Barkley Sound stocks.

Roe yield

The quality of roe was checked by processing with brine, using a I to V rating scale, category I being the highest ranking (see Section IX, Cooperative Studies, Roe Yield). In the present work, most sex ratios were very close to 1:1 male-female, hence were not included in the roe yield calculation.

4. DENSITY EFFECTS

In the previous year's impoundment study, a clear relationship existed between stocking density and mortality (Brett and Solmie 1982). The increase in mortality at higher densities and longer impoundment duration led to the suggestion that stocking density for impoundment purposes should not exceed 8 kg/m^3 (0.5 lb/ft^3). In 1982, densities in 3 experimental netpens (H1, H4, H5) were chosen to complement existing data. As well, the commercial-test pens and their monitor netpens were stocked to 8 kg/m^3. Results of the 2 years are given in Fig. 4. While the 1981 results are described equally well by linear and power relationships (e.g. $y=39.45x^{1.358}$ for the 110-day curve, $r=0.98$), the 1982 results show no clear pattern. Disease outbreaks which occurred in 1981, particularly at 16 kg/m^3 density, did not occur in 1982 at similar density. The season was marked by exceptionally good survival to spawning at the higher densities. Of interest is the fact that for 35 days from 15 February 1982, pen H8 was held at over 28 kg/m^3 density with only 5% mortality (including fish injured in catching and transporting).

In the 1982 season, developing signs of stress were noted in regular sampling, principally the subcutaneous hemorrhaging mentioned in Section VIII (2). The fact that stress, so indicated, did not develop into heavier losses and disease outbreaks is possibly only fortuitous. Monitoring of fish health in our experimental stocks (Section IX) did reveal increasing levels of at least one pathogen, viral erythrocytic necrosis. Practical experience in much higher-density impoundments such as commercial roe-on-kelp ponds leaves no doubt that higher density often results in substantial mortality even over short periods of a few weeks duration (Shields and Kingston 1982).

5. TIME OF CAPTURE

Approximately one month after the commercial-test and experimental netpens had been stocked, we returned to the catching area. Using the MARY ROBERTA and LIVEWAY as before, we made a set on 15 February, and brought a barge-load of herring to the Departure Bay site. While the vital statistics of this late catching indicate some differences, notably size and stock age structure [Table 2, and Section VII (1)], we feel that the differences arose from the catching method, and that we fished the same stock as in January (we believe that our February set skimmed the top off the target school).

The fish were placed in netpen H8 until that pen was required in the commercial sale operations. On 22 March, the bulk of the late capture stock was harvested for roe extraction, and a small quantity retained in a 3 m × 3 m × 4 m netpen at a density of 8 kg/m3. Survival to harvest was good (94.5%), and with a slight excess of males (54%), the roe content at point of sale was acceptable (10.9% by the standard DFO Fisheries Officer field test). Maturation progressed with no difference from the main stock, peaking within 1 to 2 days of the January capture group (Fig. 5, Fig. 6). Spawning occurred at the same approximate time, day 115 (25 April, 69 days after catching), as in early capture stock, and was not accompanied by any immediate increase in mortality. Care had been taken to ensure that nets used for the late-capture stock were as well-fouled as those of the main stock, in terms of time submerged. Survival to the first week of May was 87%.

6. SALINITY AND TEMPERATURE EFFECTS ON TIME OF SPAWNING

Lots of 300 herring were held in 4000-liter tanks beginning when the source stock (from H4) reached GSI (♀)=22, on day 69 of holding (10 March). Maturation progressed in all tanks at the same rate, despite different combinations of 2 salinities (10‰ and 25‰) and 3 temperatures (8°C, 10°C, 12°C). Stocks reached GSI(♀)=25 by day 82 (23 March), only slightly behind the source stock in netpens. This delay-phenomenon was observed in tank experiments in 1980-81 also, and may be a reaction to handling stress (Brett and Solmie 1982). Survival to maturity was in all cases excellent, as it was to spawning. Differences were observed only so far as yield period was concerned; tanks at higher temperatures spawned earlier. No effect was attributed to salinity. Results of the tank experiments are summarized in Tables 3 and 4, and Fig. 7.

Temperature is clearly a controlling factor with respect to delay of spawning, hence limiting the yield period. However, no tank spawned immediately upon reaching maturity, as there was a minimum delay of 1 week until spawning. Despite full maturity, tanks at temperatures below 10°C did not record substantial spawnings, even after 40 days. Mortality in the post-spawning period rose gradually; at termination on 30 April, the tanks at 12°C averaged 44% mortality, those at 10°, 21%; 8°, 18%; and those at ambient conditions (average of 9°C), 15%. As in the netpens, when contrasted with 1980-81 results, there was no outbreak of disease. The results of the two seasons' tank experiments confirm the role of temperature in spawning control

(not maturation), and the effect of higher temperature shortening the yield period.

7. SPAWNING RELEASERS

The effect of substrate and of milt as spawning releasers was tested by the following procedures: Substrate effect was tested by holding a small stock of herring (3000 fish, 8 kg/m3) in reserve, in a well fouled 4.5 m × 4.5 m × 3.6 m netpen. The net was then changed under the fish, and replaced with a new clean net (procedure given in Kennedy 1978) when GSI samples indicated the stock to be fully mature. Effect of milt was tested in one of the ambient seawater tanks in the temperature-salinity series, when GSI(♀) had reached 25, and using ripe male gonads fresh from weekly samplings.

In the substrate test, herring were judged mature on day 74 (15 March). On 7 April, 97 days after capture, the net was changed. The replacement net was newly made, bright white, and became heavily covered with spawn by 10 April. Spawning began on the afternoon of 9 April, and was heaviest during hours of darkness. No other pens spawned at this time precisely, and we conclude that the main stimulus to spawn came from the substrate change to an unfouled, smooth, soft surface.

In the milt-effect test, fresh ripe gonads were used to prepare milt suspensions giving a milt concentration in the tank of 0.30 ml/ℓ, as reported by Alderdice and Velsen (1978) for level of milt used in successful fertilization of herring eggs. Milt was added on 3 occasions after GSI(♀) reached 25, with no effect on spawning (17, 24, and 31 March). The concentration of milt was sufficient to heavily cloud the water in the tank, which was allowed to stand without dilution for a period of 2 to 6 hours. The herring showed no spawning behavior whatsoever, appearing only to be agitated, swimming at approximately twice the normal speed (i.e. 45-60 cm/sec. estimated). Within hours of water circulation being restored, the tank was clearing and they had settled down. By the time the tank experiment was terminated, on 30 April, only 25% of the stock in the tanks had spawned.

8. BIOMASS ESTIMATION

Some reported methods of estimating the amount of herring in an enclosure show promise, e.g. use of Doppler-effect sonar calibrated to known masses of fish (Pincock & Easton 1978, Anon. 1980). Others are less practical, such as photography or counting tubes admitting one fish at a time, while some practical methods require much skill, such as the trap-fisherman's method of a taut plumb-line, slowly towed through a mass of fish (individual skill correlates the activity of the plumb-line with total weight of fish). Mark-recapture was used in the first season of the present impoundment study, but gave less precise results than were desired (Brett and Solmie 1982).

In the current season, we relied entirely upon subjective visual estimates, except in those cases where a fish transfer was done by the trough method, allowing fish to be counted individually (method described in Brett and Solmie 1982). Our charter agreements were written on the basis of 50 tons of herring to be delivered. From the weigh-out at the time of the commercial sale, and accurate weights from the experimental pens, the actual quantity delivered was 47.9 tons, an error of 4.2%. Our own experience with selling 5-ton lots from the commercial-test pens indicated that, with experience, visual estimates of a similar accuracy were not difficult to make, when the subject stock was contained in a relatively small enclosure such as a live-barge or a 7.5 m × 7.5 m × 5 m netpen.

IX. COOPERATIVE STUDIES

1. DISEASE

Herring from a high-density netpen (16 kg/m3) were monitored for disease over a 5-month period from late January to late June 1982. Fish sampled randomly every 2 weeks were examined for viral erythrocytic necrosis (VEN), systemic bacteria, parasites, blood hematocrit values, and general histopathology.

The incidence of VEN increased from initial levels around 3% to as high as 70% near the end of the sampling period, being higher in the high-density netpen than in samples taken from a lower-density netpen. Bacterial isolates obtained from kidneys of diseased herring were shown to be acutely pathogenic in juvenile herring. Definitive identification of the causative organism has not yet been carried out. Results of antibiotic sensitivity tests indicate oxytetracycline to be the most effective treatment. Neither VEN nor the bacterium observed were responsible for serious mortality of any stock during the impoundment period, although a VEN outbreak may have been developing when sampling was stopped in June.

2. ROE QUALITY

Sampling of 10- to 30-kg lots of herring from netpen H7 (monitor pen for L1) was started on 5 March 1982 and carried on every 3 to 4 days until 15 April. Weekly samples were also taken from pen L2, from 15 April to 12 May. The roe was either frozen or processed in brine solutions, and subsequently assessed for quality using a 5-category scale (color, shape, firmness, length, and flavor). The proportion of unripe roe decreased rapidly from over 80% on 1 March to less than 5% after 18 March. The highest level of good quality roe was reached by the 4th week of March, and remained high for approximately 3 more weeks until the first partially-spent fish turned up. The range of percentage Grade I + II roe for the period was 71 to 89. Most

roe remained high in quality until after 15 April, by which time over 25% of the herring were completely spawned out.

Freeze-processing of roe yielded a higher percentage of finished product than did brine-processing (31.4% vs 24.9%, difference significant at 95% confidence level). The proximate composition of the roe was in the normal range for commercial samples from wild stocks. Moisture ranged from 67.2% to 77.8%, protein from 16.9% to 26.2%, lipid from 2.9% to 6%, and total ash from 1% to 1.9%.

3. ECONOMIC ASSESSMENT

The results of the Pacific Biological Station roe herring impoundment research indicate the practical feasibility of impounding maturing herring for sac roe. The uniform maturity of the impounded herring and the fact that they can be handled in smaller quantities if desired suggests that quality and yields should be similar to, if not better than, gillnet-caught herring and definitely superior to seine-caught herring. The price expected for impounded herring should therefore be similar to the price of gillnet herring, or greater if the relative advantage in quality and yields can be maintained. The expected price differential remains uncertain pending a valid comparison between impounded seined herring and gillnet-caught herring, since seined herring will tend toward a smaller average roe size; roe size is an important factor determining the grade in the Japanese market.

The present analysis indicates that impounding herring for roe could lead to large benefits for the pond operator. Benefits are related to the scale of the operation; decreasing the scale from 200 tons to 50 tons reduced both the benefit-cost ratios and the net benefits (present value calculated over 10 years at a 10% discount rate), but the results remained highly favorable even for a 50-ton operation. The range of prices considered affected the magnitude of the results but not the conclusions.

In assessing the economic feasibility of an impoundment operation, two viewpoints must be considered; the operator's, and society's as a whole. For the operator, the relevant benefits and costs are the ones he receives or incurs directly. Society's viewpoint must consider the operator's overall gains and the costs of allocating related resources to the project, such as additional enforcement costs incurred by the Department of Fisheries and Oceans. Much of such an evaluation depends on the management strategy for the entire roe herring fishery: where the stocks are coming from and who the potential pond operators are. From society's standpoint, the relative price advantage factor, and the overall management strategy, play a much greater role. The critical factor is the source of the herring taken for impoundment. If these herring are taken from stocks which cannot otherwise be exploited, the results are extremely favorable. Net social benefits are high, as are benefit-cost ratios, no matter on what scale the project is carried out. If, however, the impoundment herring are taken from stocks which are already being exploited, the overall gains are reduced by the revenue lost from the other fisheries. The scale of the project and the price of the impounded herring relative to other roe herring become much more critical. A

50-ton project does not yield positive net social benefits with the relative prices considered here if the fish are taken from exploited stocks. A 100-ton project has positive net social benefits only if prices exceed gillnet prices and the stock is taken from the seine allotment. A 200-ton project yields positive results for all prices if the stocks are taken from the seine allotment. Benefits remain positive if the 200 tons are taken from the mixed seine-gillnet fishery, as long as the most optimistic price estimate is used. Table 5 gives a detailed breakdown of the benefit-cost analysis for 3 sizes of impoundment.

The results of the analysis suggest that roe herring impoundments have the potential for substantial economic benefits. A portion of these benefits are due to the improved quality and yield possible, particularly when compared to the current seine fishery. However, the major portion of the benefits comes from the fact that it would be possible to fish small stocks which are presently unexploited or unexploitable. One or two vessels fishing for an impoundment could be allowed to fish a small stock where the 60-odd seiners that would show up for an opening could not.

For a particular catch, the biggest potential beneficiaries from impoundment would undoubtedly be the seiners. Not only are they the gear type suited to this type of operation, but they could also expect to gain price increases from $200 to $350/ton according to these estimates. Impoundment also offers one method of more easily achieving the target seine allocation of roe herring, by improving the manageability of the open fishery through transfer of seiners to impoundments.

Though some uncertainty surrounds both the expected revenues and costs from roe herring impoundment, it seems clear that the potential rewards could be substantial. This is especially true if impoundment provides the opportunity to use stocks which are not unexploited. If roe herring impoundment lives up to this potential, the next challenge will be to find a fair and equitable way to distribute these rewards.

X. COMMERCIAL-TEST OPERATION: SALE AND PROCESSING

Herring held in the new large netpens were put up for bids from commercial processors. The successful high bidder was Pisces Trading Company of Richmond, B.C., at a price of $1151/ton (Canadian). At the time the tender was awarded, prices for roe herring were fluctuating slowly upwards as the season developed. By comparison to gill-net caught roe herring at this time, the price was favorable, although late-season prices on the North Coast eventually exceeded $1400/ton.

For servicing the sales, a smaller 7.5-m × 7.5-m × 5.4-m netpen was used for transfer of 5-ton lots from the large 27.7-m netpens, in the manner described in Section V (2).

1. DOCKSIDE

Herring delivered live to dockside at the Pacific Biological Station were brailed out of the transfer netpen in lots of approximately 125 kg. Buyer-supplied wooden totes of nominal half-ton capacity were prepared by inserting a 5-mil polyethylene liner bag, into which 4-6 shovelfulls of crushed ice were placed. Brailer-loads of herring were added, to final weights ranging from 180 to 545 kg, followed by another 4-6 shovelfulls of ice (contract specified 227 kg/tote, i.e. half full, however the buyer chose, for reasons of road safety with the truck used, to load forward totes heavier than those at the rear). When fully loaded, the totes measured 1 m depth of herring. The exteriors of the totes, including lids, were painted with aluminum paint for reflection of heat. Normal practice was for the truck to load up two empty totes with ice from the freezer plant on the night before making a fish pick-up. Arriving on the first morning ferry from Horseshoe Bay put it at dockside by 0830. Loading usually took 4 hours or less for a 5-6 ton load. Most of the afternoon was taken up with the ferry-trip back to the mainland, and driving to the freezer plant. Fish were usually processed starting at 1900 or 2000; at worst, they could be 14 hours from death to freezing. Including 2.3 tons late capture stock, a total of 42.3 tons was sold.

2. FREEZER PLANT

Totes had been unloaded from the truck prior to 1900, and kept indoors at the plant at approximately 5°C. For the 'Individual Quick Freezing' process, a crew transferred shallow basket-loads (50-60 fish) from the totes to sorting tables, where they were manually spread out on large freezer trays, 1.2 m $\times$ 0.6 m, so that there was only incidental contact between fish. Trays loaded on racks were wheeled into the blast freezers, and frozen to -20°C. By the time processing for freezing began, herring were in various degrees of rigor. This factor would have hindered some processes e.g. sexing or size-grading by machine. Noticeable also was the fact that near the bottoms of the totes, roe (as well as milt) was squeezed out of some fish, resulting in a loss in roe index of approximately 1%. The herring were not washed during this stage of processing. As a basis for freezer charges, fish were weighed here in daily lots as they were handled. Early lots were stored frozen for up to 3 weeks, others for less. Freezing yielded a weight gain of 6.05% in bulk weight.

3. ROE EXTRACTION

Frozen fish were transported from the freezer plant in the same silvered totes, covered by black polyethylene. At the roe extraction plant, enough fish for a day's work were spread out on the plant's concrete floor to thaw overnight. Once thawed, they were placed back in polyethylene-lined totes, 227 kg per tote, with fresh water added to reduce pressure on the lower

layers of fish. Each tote was drained and dumped out on a belt manned by the roe-extraction crew. For the 10-ton-day lots processed, this crew numbered 17. Fish were individually opened with round-tipped knives or pointed chopsticks, males and carcasses sorted to one water-fed gutter, manually-removed roes to another. Shallow open-weave baskets (plastic) were placed under the roe gutter, removed when full, and weighed. There was no grading of incoming whole fish, nor of extracted roe, as quality of the product was consistently high, and the incidence of immatures very low. Weighed roe-baskets were rinsed once in a freshwater bath, then brined twice in 100% brine solutions for 2 hours, then finished for 24 hours in a third solution at 100% (i.e. fully saturated marine salt solution). Brined roes were quite firm to the touch, whereas the freshly-extracted roes were quite soft and easily broken. Brining also removed most of the visible blood present in the ovary blood supply vessels. Broken or damaged roes constituted a notably low fraction; incidence of first-grade roes after final brining was 91-92%. The final stage of processing for export, placing in square white pails, took place with no final sort; all roes went as first grade. As well, pails were loaded to 17.3 kg rather than the customary 18.2 kg, again due to the high quality level. For this bucketing procedure, 17.3 kg of roe was placed in each pail, a generous scoop of coarse marine salt added on top, the pail filled with fresh water, and tightly capped. Total roe yield was 5910 kg after brining, or 15.37% of the purchase weight.

Carcasses and males collected at the end of the processing line were loaded in half-ton totes and removed daily for processing into meal, probably destined for pet food ingredients. Roe extraction plant staff expressed satisfaction with the quality of the impoundment herring, particularly for the increase in undamaged roes over that possible with pump-discharged, seine-caught herring, unloaded at the plant with the expediency necessary in the peak conditions typical of the roe fishery. The uniformity of the impoundment herring was also remarked upon, inasmuch as practically all herring had fully-developed ovaries, including very small fish. There appeared to be no incidence of ovaries too ripe for processing. The general condition of the herring at the extraction plant, when wear from freezing and thawing was discounted, was good. The fish were bright, only slightly descaled if at all, and there were extremely few external signs of disease due to stress or other factors.

The first load of herring was sold on 22 March, and the last on 5 April, for a harvest period of 14 days. No spent fish turned up during processing.

XI. SUMMARY STATEMENT

The 1981-82 roe herring impoundment operations served 2 objectives: confirmation of results obtained in the first year of operation, and assessment of several key additions, notably the commercial sale and processing of the roe product, and the effect of late capture.

Initial results confirmed in the present report include: normal progress of maturation over an impoundment period of 3 months, followed by an extended holding period of about 40 days at full maturity without spawning; improvement of roe grade during early maturation resulting in potentially high quality roe yield for at least 3 weeks; and positive correlation between higher water temperatures ($\geq$10°C) and earlier spawning within a stock.

New findings include: high quality and market acceptance of impoundment herring roe; excellent holding and handling characteristics of large 20+ ton netpens; extended harvest period for roe, with uniform quality of harvest available over at least a 2 week period; and some independence of time of capture, herring caught one month after the main catching maturing similar to the main stock in all respects.

We recognize once again that a major factor contributing to success of the impoundment program was the experience and expertise of the fish culturists involved. Herring were given careful handling from capture to sale, stress was at all times minimized, and herring were induced to swim from enclosure to enclosure, so as to avoid physical damage. The results of our present studies on density-mortality problems bear further investigation.

In general, the second year of the impoundment study increases confidence in the expectation of long-term yield periods (30 days or more) for commercial roe herring impoundments. Although caught by seine, impoundment herring may be expected to bring a higher market price by virtue of the facts that harvest can be delayed until all fish have reached maturity, and that no spent fish occur for some weeks. While the selectivity of a gillnet can ensure a larger mean roe weight, impoundment operators may expect to equal or exceed returns from a gillnet fishery by timing of sale in response to market conditions, and through options for use of impoundment herring in alternative products and fisheries. The third and final year of the impoundment program, including a full scale commercial operation at a field location, should substantiate the impoundment results and projections now in hand.

XII. ACKNOWLEDGMENTS

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Scientists G. R. Bell (disease) and J. Cheng and H. Tsuyuki (roe quality) and Department of Fisheries and Oceans economist M. MacGregor submitted reports on special aspects of the study, once again enhancing the study with a wider scope of inquiry than would otherwise have been possible, and for which we are grateful. The continued joint study of commercial and research aspects of herring impoundments was made possible by co-funding from the Fisheries Development Program, with supplementary input from the Department of Indian and Northern Affairs.

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Table 1. Weekly records of average environmental conditions monitored in the impoundment area (1982).

Week		t°C	Sal.‰	Turb. (m)
Jan.	4-10	6.1	27.2	10.8
	11-17	6.7	27.4	9.7
	18-24	7.0	26.6	11.3
	25-31	7.7	25.0	6.8
Feb.	1- 7	7.7	26.7	11.4
	8-14	6.8	26.8	7.0
	15-21	7.9	26.1	6.7
	22-28	6.9	26.1	6.9
Mar.	1- 7	7.2	26.9	5.3
	8-14	7.6	26.3	8.5
	15-21	7.7	27.2	12.1
	22-27	8.2	27.4	7.9
	29- 4	7.8	27.6	6.2
Apr.	5-11	8.5	26.1	5.9
	12-18	8.2	27.6	7.9
	19-25	10.6	27.6	7.1
	26- 2	10.0	28.4	10.9
	$\bar{x}$	-	26.88	8.38
	SD	-	0.78	2.13
	SE	-	0.19	0.52

Table 2. Vital statistics of experimental and production lots of herring in netpens with their survival maturation time and yield period in response to conditions of impoundment listed in Table 4. Duration of impoundment from 09 January to 05 May 1982.

Netpen No.	No. of fish	Length $\bar{x}$, mm	Weight $\bar{x}$, g	♀ %	Density kg/m^3 (lb/ft^3)	Survival, %, to Mature	Survival, %, to Spawn	Days to GSI(♀)=25	Days to 1st spawn	Yield period days
H1	8,100	205	118	51	14.8 (0.9)	93	91	74	125	51
H4	12,000	210	128	52	6.8 (0.4)	91	90	67	123	56
H5	22,000	209	124	58	11.6 (0.7)	92	89	70	118	48
H6	3,100	207	123	50	7.1 (0.4)	97	96	72	110	38
H7	3,600	206	122	55	8.2 (0.5)	95	95	70	91	21
H8	59,900	200	107	46	28.2 (1.8)*	96	88	68	115	47
L1	153,600	211	132	61	10.1 (0.6)	91	-	71	Sold	
L2	136,600	207	123	60	9.1 (0.6)	98	-	71	Sold	

*After 35 days, density was reduced to 8.0 (0.5)

Note: densities calculated on actual rather than nominal netpen dimensions. See Table 4.

Table 3. Vital statistics of experimental lots of herring in tanks, with their survival, maturation time and yield period in response to holding conditions listed in Table 4. Fish were held in tanks from 10 March to 30 April 1982, 300 fish per tank, at a density of 9.6 kg/m^3 (0.6 lb/ft^3).

Tank No.	Length $\bar{x}$, mm	Weight $\bar{x}$, g	♀ %	Survival,(%) to Mature	Spawn	Days to GSI(♀)=25	1st spawn	Yield period, days
1	208	111	42	100	92	9	50	41
2	200	116	46	100	76	6	53	47
3	214	130	52	99	94	13	24	11
4	214	135	52	100	96	5	26	21
5	215	133	50	100	95	6	20	14
6	197	114	45	100	88	7	19	12
7	208	119	50	100	88	7	36	29
8	209	127	44	100	93	6	31	25

Table 4. Experimental conditions imposed on impounded herring to examine effects of stocking density, salinity, and temperature. H-numbers apply to netpens at the Departure Bay fish farm, T-numbers to fiberglass tanks at the Pacific Biological Station.

Pen no.	Nominal net* size, LWD, m	Subject	Temperature	Salinity
H1	4.5 × 4.5 × 3.7	Density-stress	Ambient	Ambient
H4	7.5 × 7.5 × 5.2	Density-stress	Ambient	Ambient
H5	7.5 × 7.5 × 5.2	Density-stress	Ambient	Ambient
H6	4.5 × 4.5 × 2.7	Monitor 1	Ambient	Ambient
H7	4.5 × 4.5 × 2.7	Monitor 2	Ambient	Ambient
H8	7.5 × 7.5 × 5.2	Late capture	Ambient	Ambient
T1	4000ℓ	Spawn-control	8°C	10‰
T2	4000ℓ	Spawn-control	8°C	25‰
T3	4000ℓ	Spawn-control	10°C	10‰
T4	4000ℓ	Spawn-control	10°C	25‰
T5	4000ℓ	Spawn-control	12°C	10‰
T6	4000ℓ	Spawn-control	12°C	25‰
T7	4000ℓ	Exp't control	Ambient	Ambient
T8	4000ℓ	Exp't control	Ambient	Ambient

*Actual volumes enclosed, measured directly and used in density calculations, are slightly different in all cases.

Table 5. Present value of benefits and costs for 3 sizes of roe herring impoundment over a 10-year period, discounted at 10%. Dollar values shown in thousands.

A. From the pond operator's viewpoint:	Present value of benefits			Present value of costs[1]			Benefit/cost ratio			Present value of net benefits		
	200t	100t	50t	20t	100t	50t	200t	100t	50t	200t	100t	50t
Price: $1010/ton	1,230	620	310	210	160	150	5.8	3.9	2.1	1,020	460	160
$1070/ton	1,310	660	330	210	160	150	6.2	4.2	2.2	1,100	500	180
$1150/ton	1,400	700	350	210	160	150	6.7	4.4	2.3	1,190	540	200
B. From society's viewpoint:	**Gain in benefits**			**Increased costs**			**Benefit/cost ratio**			**Net benefits**		
Source: 1. Unexploited stocks												
$1010/ton	1,230	620	310	127	100	110	9.7	6.2	2.8	1,100	520	200
$1070/ton	1,310	660	330	127	100	110	10.3	6.6	3.0	1,180	560	220
$1150/ton	1,400	700	350	127	100	110	11.0	7.0	3.2	1,270	600	240
2. Mixed seine-gillnet												
$1010/ton	20	10	5	127	100	110	0.2	0.1	0.04	-107	-90	-105
$1070/ton	102	51	25	127	100	110	0.8	0.5	0.2	-25	-49	-86
$1150/ton	190	95	48	127	100	110	1.5	0.9	0.4	63	-5	-62
3. Seine allotment only												
$1010/ton	150	75	38	127	100	110	1.2	0.7	0.3	23	-25	-72
$1070/ton	230	115	58	127	100	110	1.8	1.2	0.5	103	15	-52
$1150/ton	320	160	80	127	100	110	2.5	1.6	0.7	193	60	-30

[1]Assumes fixed real costs, and replacement of capital items in accordance with expected life of the asset.

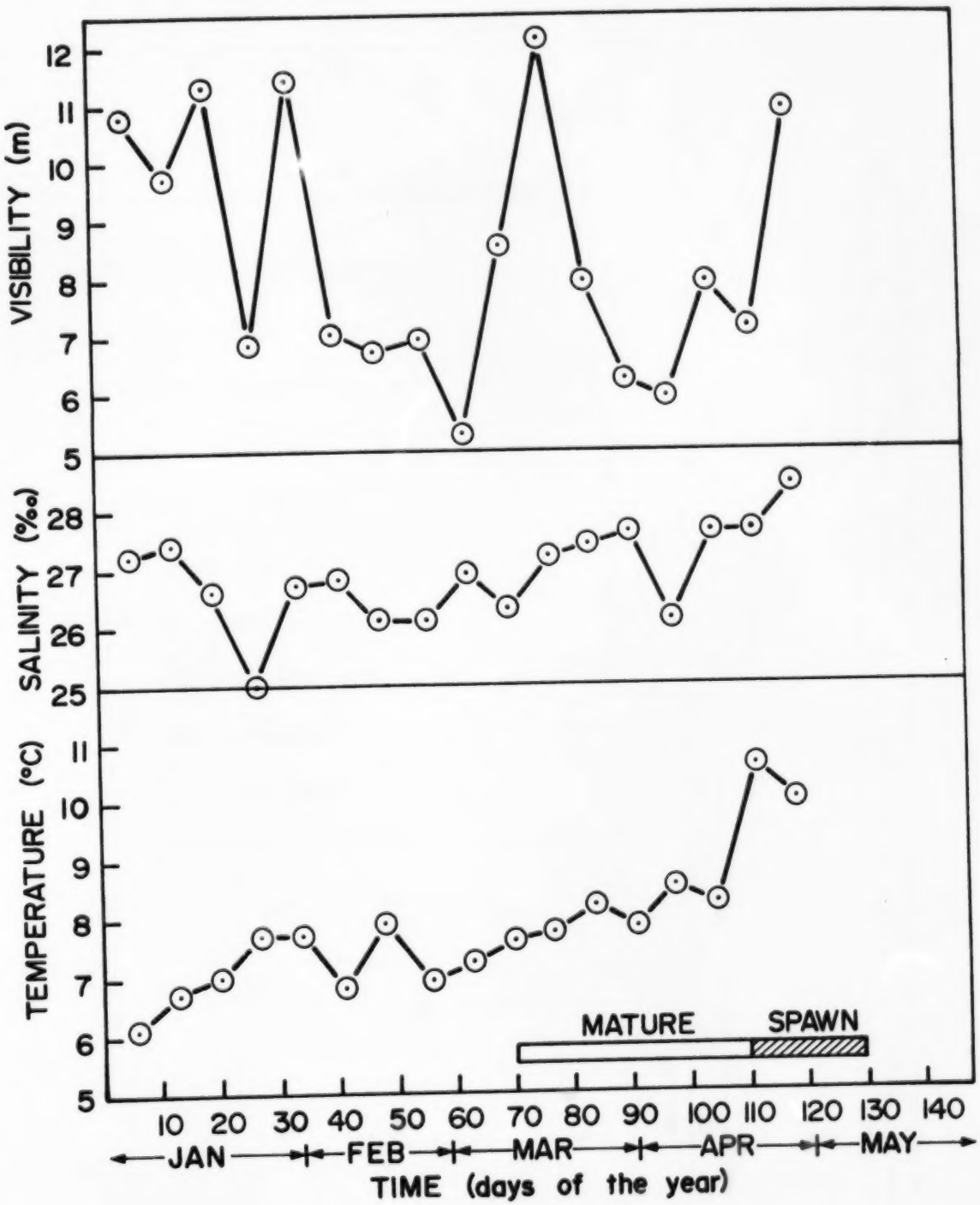

Fig. 1. Record of environmental conditions, January to May 1982 at the impoundment site, Departure Bay. Points are weekly means, and the bar to lower right indicates progress of maturation in herring stock.

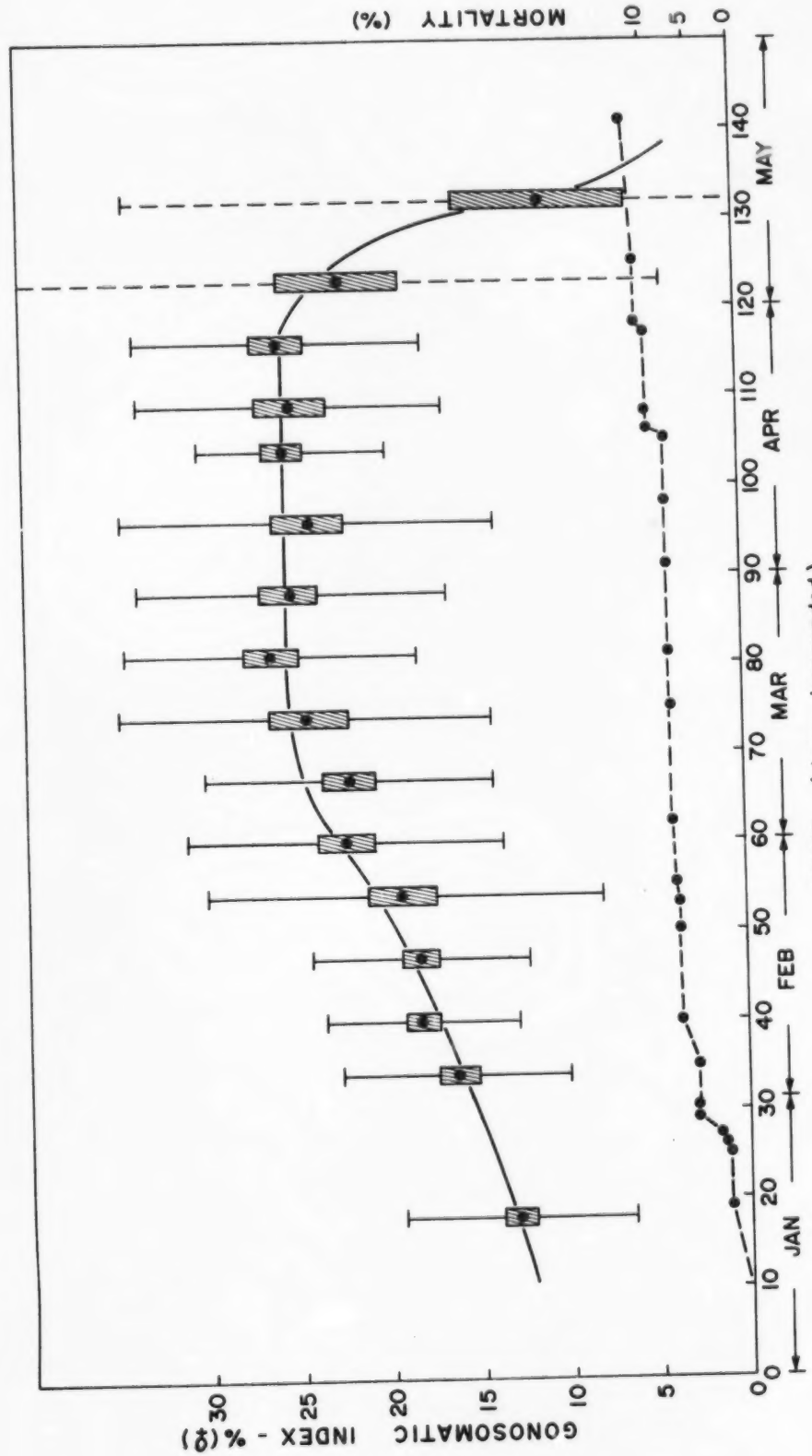

Fig. 2. Change in gonosomatic index of female herring held in netpen H5 at Departure Bay fish farm, 9 January-20 May 1982 (Mean $\pm$ 2SE, $\pm$ 2SD). GSI=25% occurred on day 70 (11 March) and spawning occurred 48 days later, on 28 April. Lower line gives cumulative mortality.

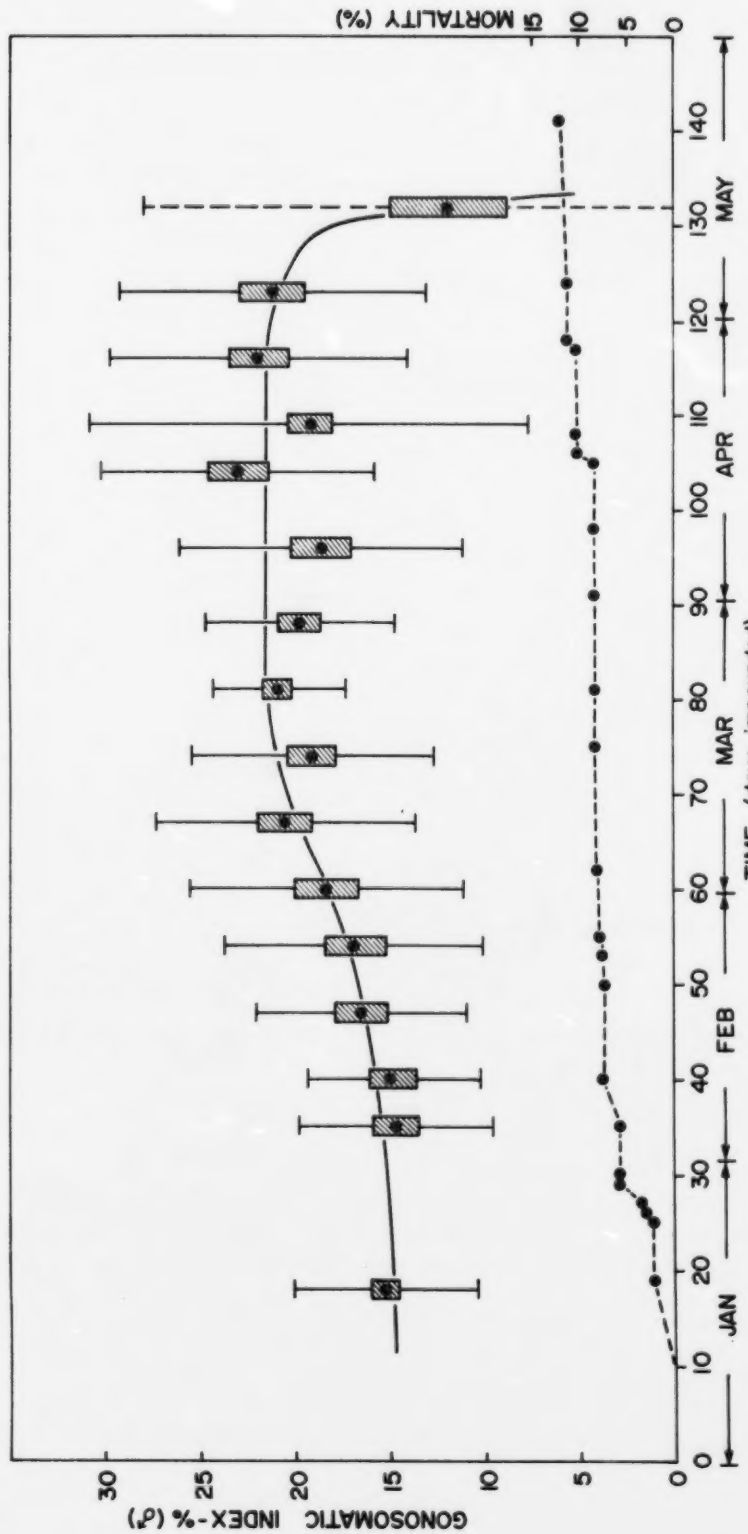

Fig. 3. Change in gonosomatic index of male herring held in netpen H5 at Departure Bay fish farm, 9 January–20 May 1982 (Mean + 2SE, + 2SD). GSI=20% occurred on day 68 (9 March) and spawning occurred 50 days later, on 28 April. Lower line gives cumulative mortality.

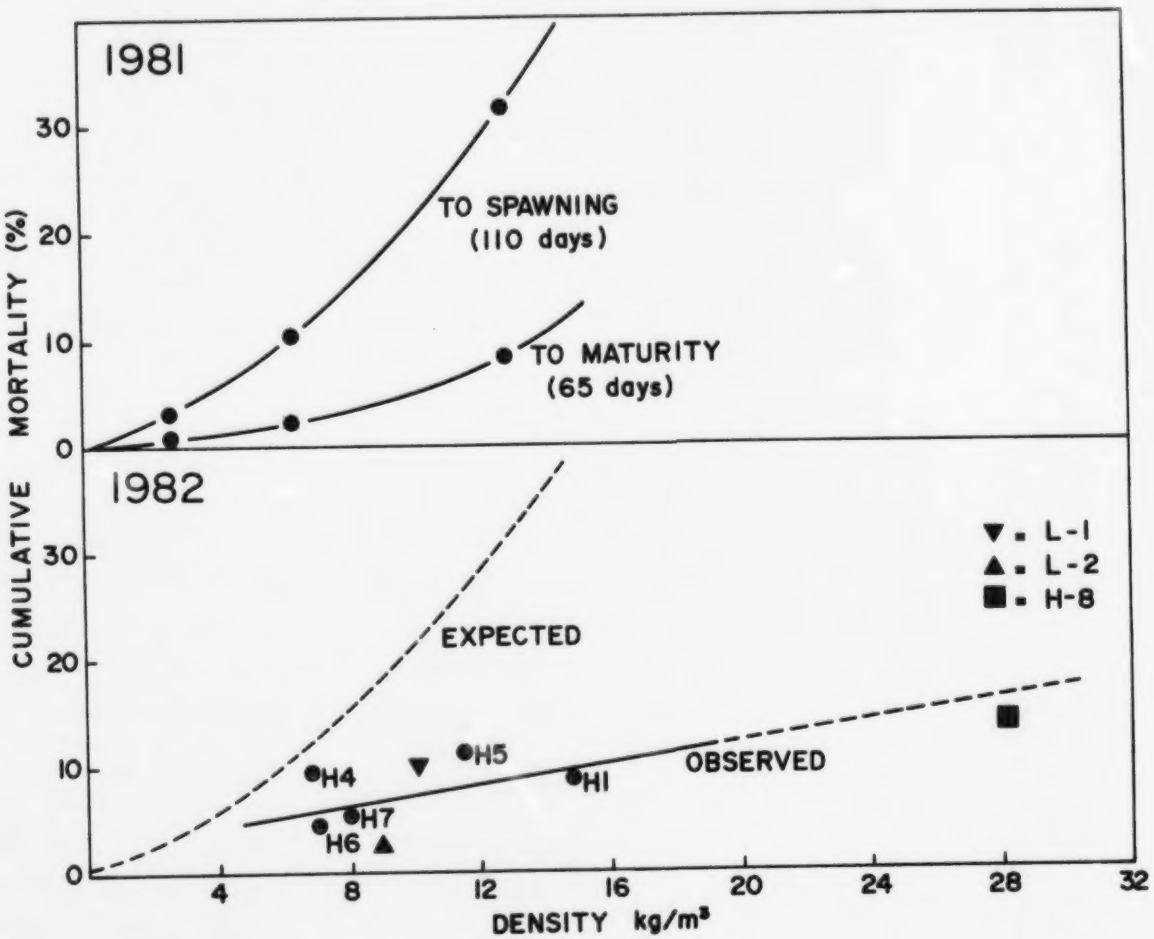

Fig. 4. Comparison of density-mortality curves for 2 seasons of impounding roe herring at the Departure Bay fish farm. Upper frame gives curves for mortality to maturity (65 days) and to spawning (110 days) for herring impounded in 1981. The lower frame shows the 110-day curve from 1981, to which netpens H1, H4, and H5 were intentionally stocked in order to confirm initial results. The results observed are shown by the straight line, $y=2.667 + 7.409x$, $r=0.44$. Additional points included are the commercial-test pens (L1 and L2) and their monitors (H6 and H7), and the late-capture group (H8); the latter was held only for 35 days from 15 February 1982.

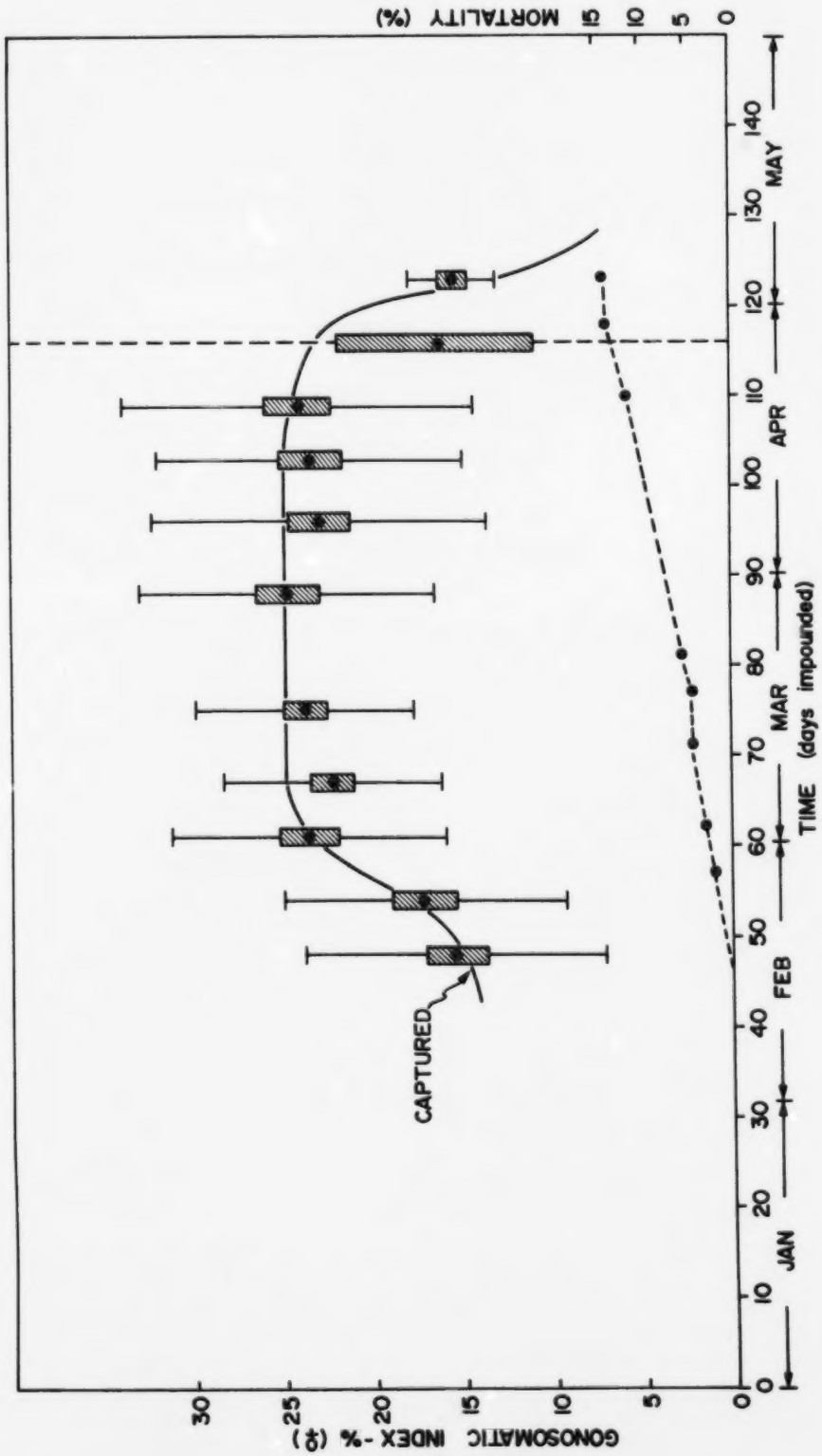

Fig. 5. Change in gonosomatic index of female herring held in netpen H8 at Departure Bay fish farm, 15 February-5 May 1982 (Mean ± 2SE, ± 2SD). GSI=20% occurred on day 71 (12 March), and spawning occurred 44 days later, o- 25 April. Lower line gives cumulative mortality.

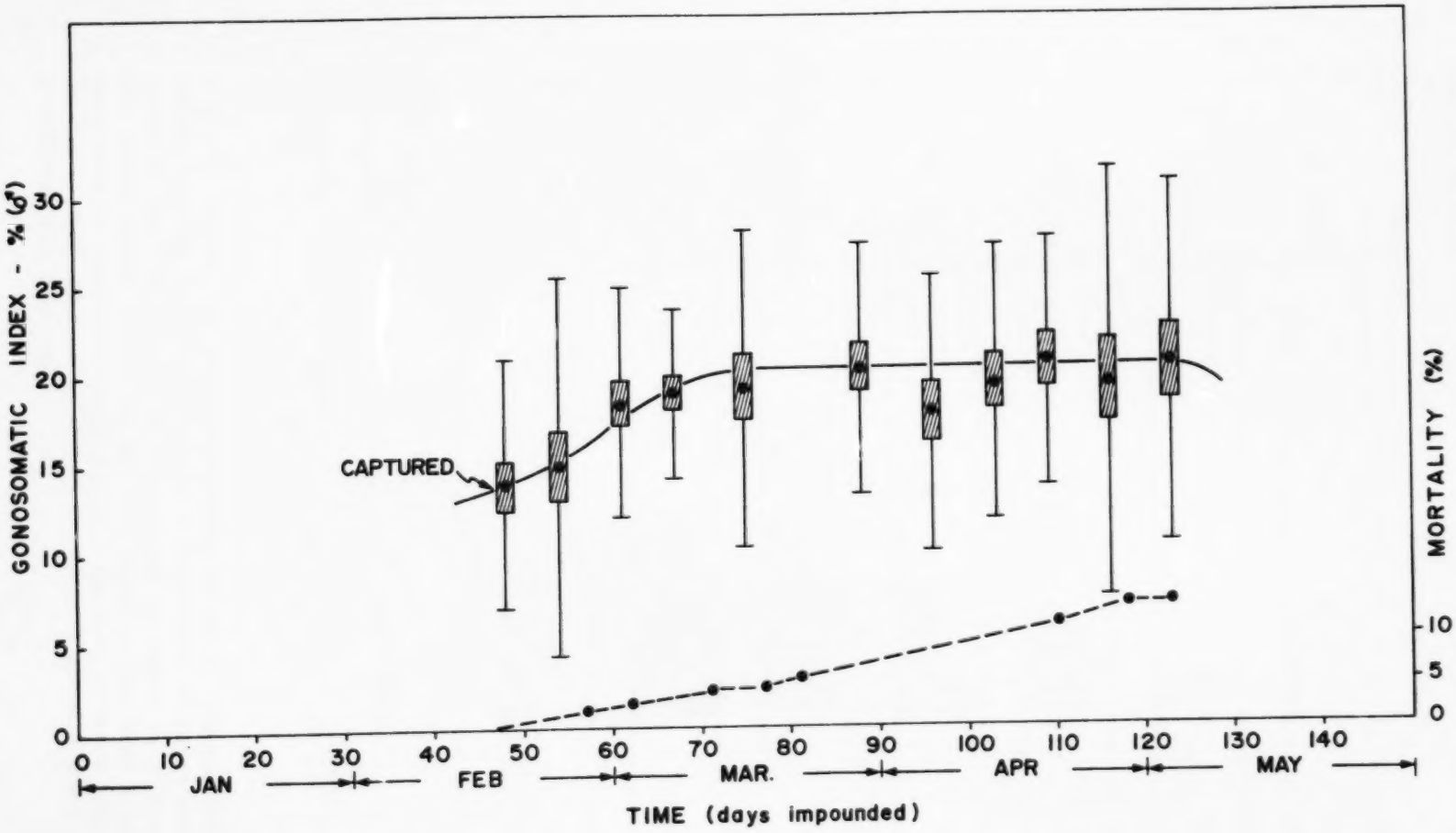

Fig. 6. Change in gonosomatic index of male herring held in netpen H8 at Departure Bay fish farm, 15 February-5 May 1982 (Mean ± 2SE, ± 2SD). GSI=20% occurred on day 71 (12 March), and spawning occurred 44 days later, on 25 April. Lower line gives cumulative mortality.

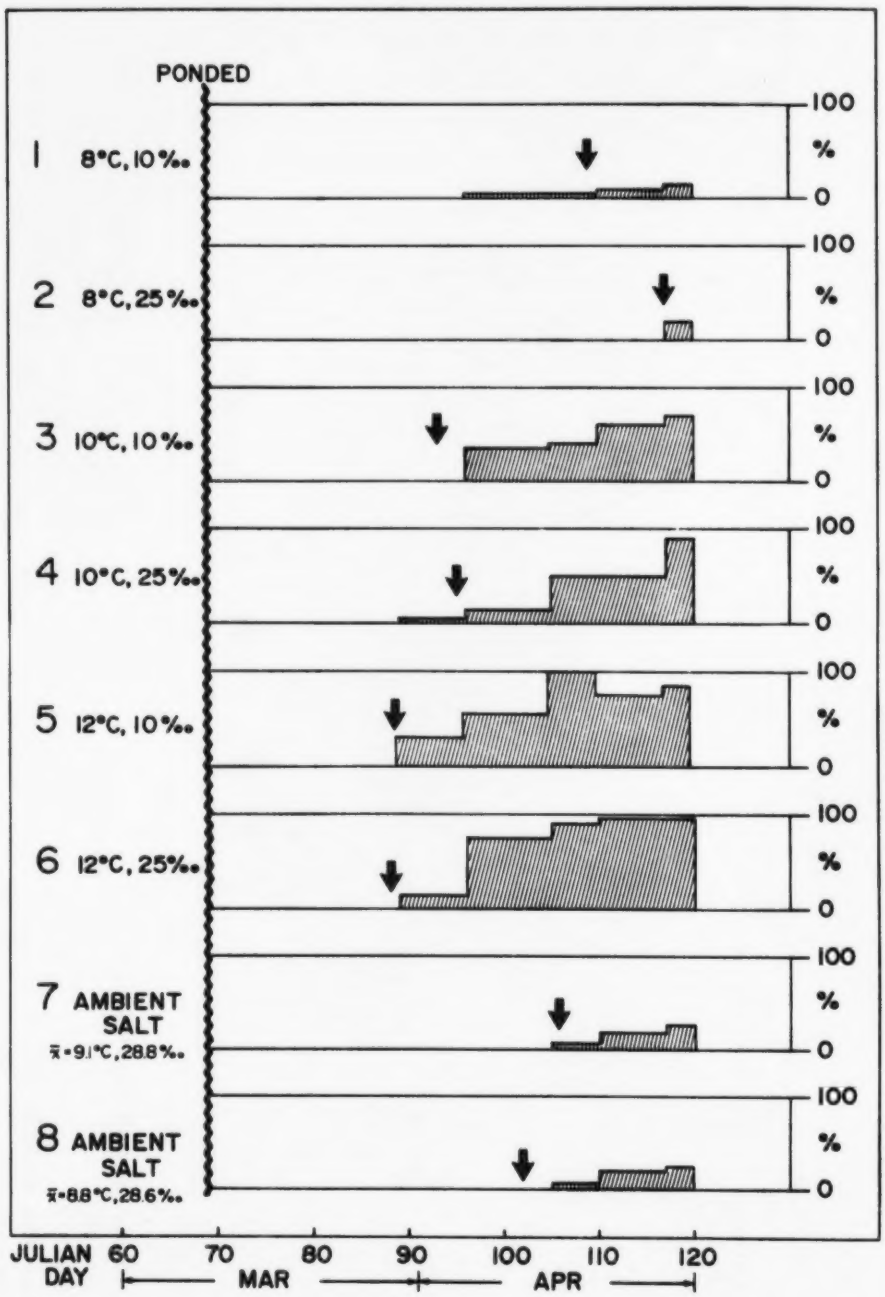

Fig. 7. Summary of percent incidence of spent spawner herring in weekly samples (n=20) from tanks at different salinity and temperature combinations. Herring were transferred to tanks on 10 March when the source stock had surpassed GSI(♀)=22%. The first spawning in each tank is indicated by an arrow. The source stock reached GSI=25% on day 75, and spawned on day 117. Table 3 gives a summary of vital statistics for each tank.

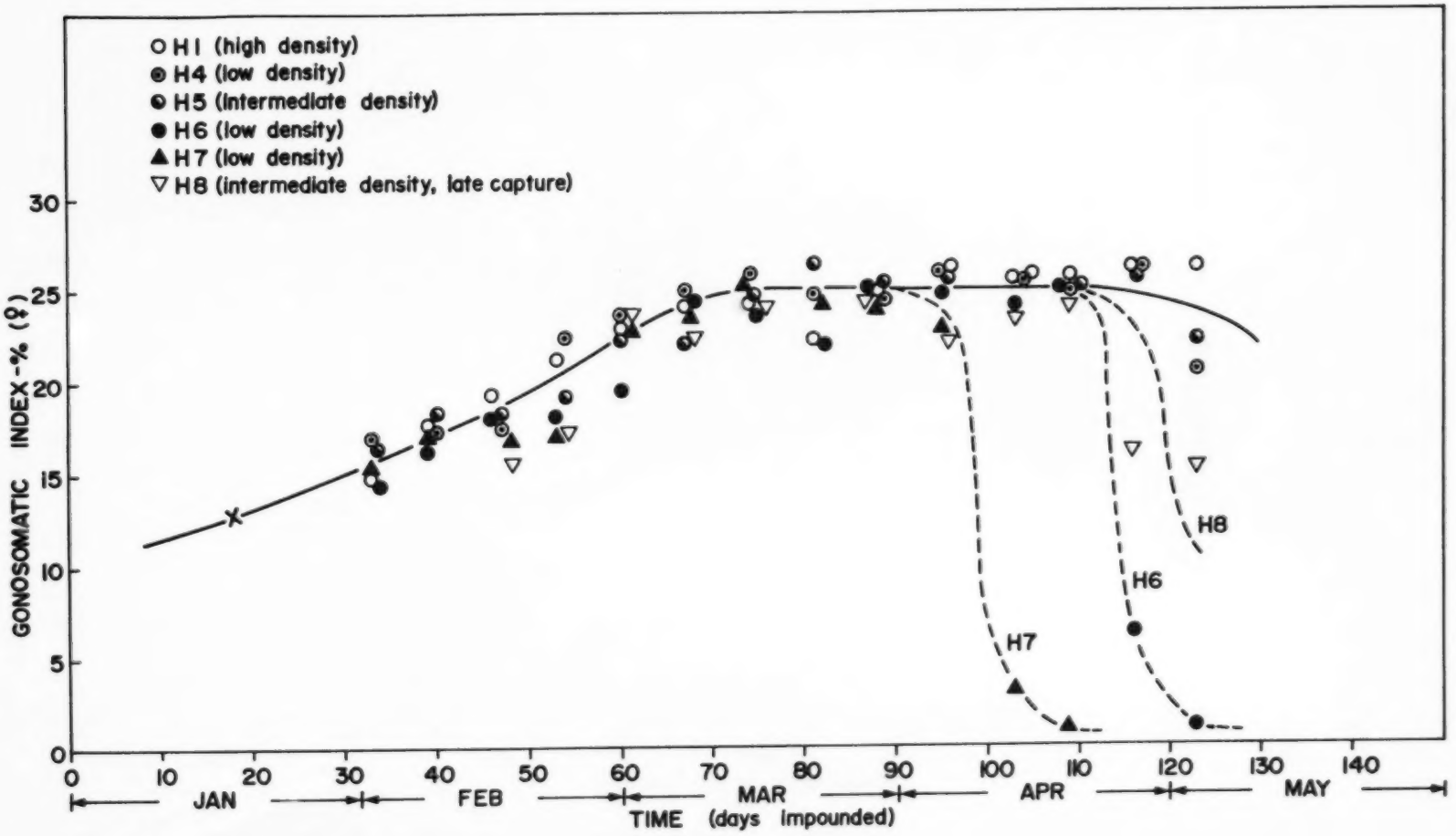

Fig. 8. Comparisons of change in mean gonosomatic index of female herring held in various netpens at Departure Bay fish farm, 9 January-20 May 1982. A common initial sample was taken after catching, on 18 January. General progress of maturation is shown by the solid line, fitted by eye. The late-capture stock, H8 was taken on 15 February. Except for one group of approximately 3000 herring, no spawning occurred until after 40 days or more delay at GSI(♀)=25.

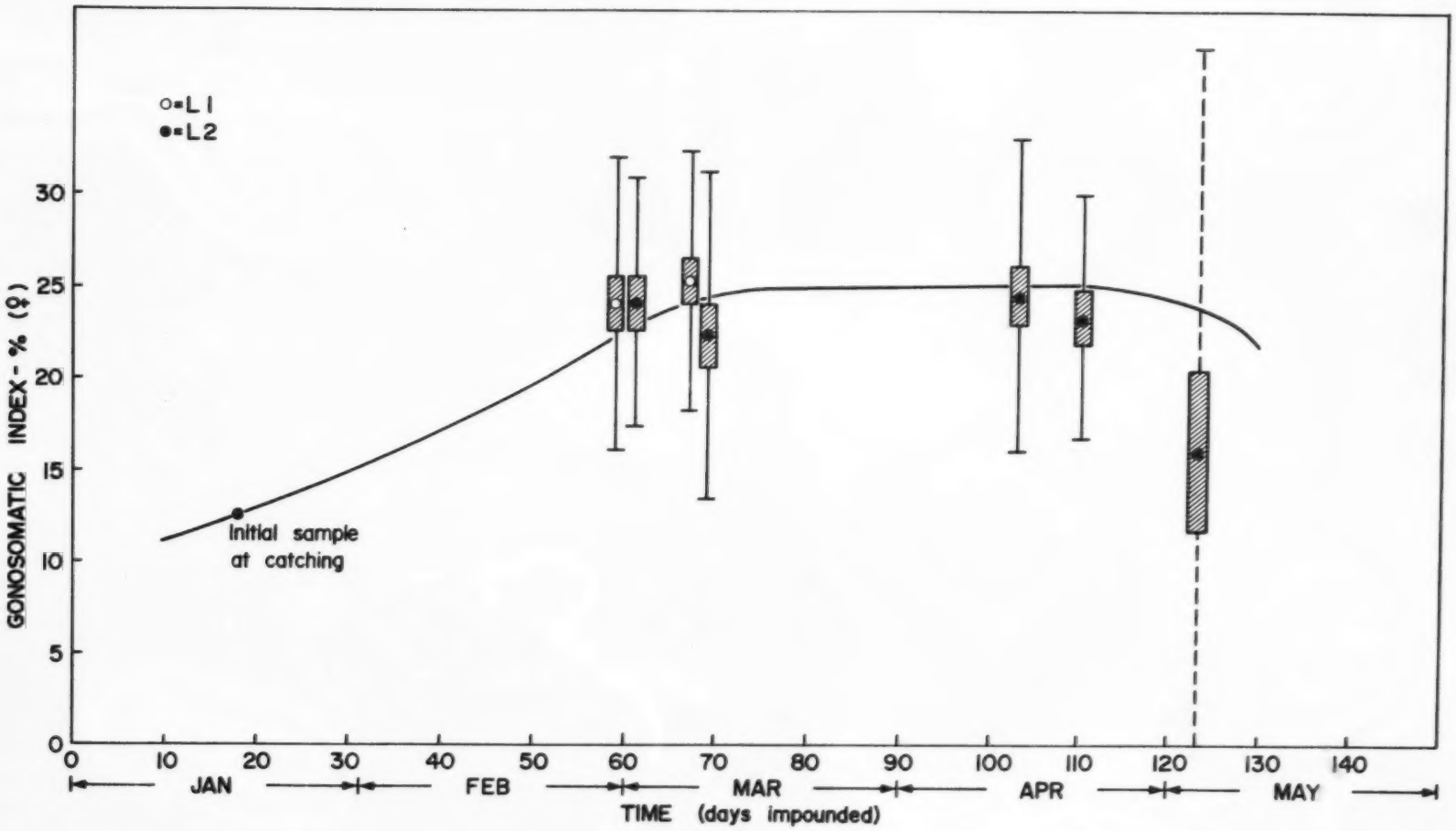

Fig. 9. Comparison of actual samples from commercial test pens L1 and L2 (mean ± 2SE, ± 2SD) with generalized curve for progress of GSI(♀) based on weekly sampling in experimental and monitor netpens (Fig. 9). Stock was held at the Departure Bay fish farm between 9 January and 20 May 1982. Pen L1 was sold by commercial auction by day 84 (25 March) while L2 was not completely sold until day 95 (5 April). Pen L2 samples after that date came from a small group of herring, approximately 3/4 ton, allowed to remain in the pen for observation. The accuracy of the monitoring concept is demonstrated by the close agreement between the generalized curve and the actual samples from the commercial-test pens.